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Current status and development policies on renewable energy technology research in Taiwan

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Abstract

Taiwan is a subtropical island nation with high dependence upon imported energy, about 97% of its energy is supplied by imported fuels. Environmental pollution and greenhouse gas emissions are becoming significant issues in Taiwan. In this regard, renewable energy like bio-gas energy, wind energy and solar energy are thus becoming attractive because the Energy Commission under the Ministry of Economic Affairs and other government energy expenditures pledged about annual US$ 100 millions in total to promote renewable energy and energy conservation based on the renewable energy development policy approved by the Executive Yuan (Cabinet) in January 2002. Also, the Taiwan government announced the ambitious target to achieve about 6500 MW of energy from renewable sources by 2020, which is equivalent to increase Taiwan's installed capacity of power supply from renewable sources to above 10%. The objective of this paper is to present an updated overview of energy policy from renewable sources in Taiwan, including the government's organizational response and special funds for supporting renewable energy promotion and technology development. Then, current status of usage and technology development of renewable energy is further addressed in this paper, concentrating on biomass energy, solar energy and wind power. Finally, the paper will focus on some integrated research and development programs to promote renewable energy technology, and summarize two research projects of biofuel energy (i.e. bio-hydrogen production and fast pyrolysis technology from organic wastes) in progress under the joint-funds of the Ministry of Economic Affairs and the National Science Council.

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Contents

1. Introduction

Although the use of conventional fossil fuel (i.e. coal, petroleum and gas) and adoption of hydropower energy provides most of the world's commercial power, their consumptions are inevitably accompanied by human activities that not only pollute and damage the environment, but also exhaust the natural resources. Nuclear energy also creates pollution problems in the safe disposal and/or storage of the resulting radioactive wastes. Since the energy crisis in the 1970s, support in several developed countries (e.g. USA, Germany, Denmark, the Netherlands and Japan) and developing countries (especially China, Indian and Brazil) had focused upon the so-called clean energy or renewable energy, especially in wind energy, biomass energy and solar energy [1]. At this moment, many public and private decision makers are thinking about how to achieve a sustainable transition away from fossil fuel-based energy technologies, and many energy proposals have been submitted and executed, like more government research and development (R&D) for renewable energy technology and energy conservation, the introduction of carbon taxes etc. [2].

Taiwan, located in the Far East of Asia, is a densely populated island nation with only limited natural resources. By the end of 2003, Taiwan's population density was high, up to 640 people/km^2 based on its total area of 36,000 km^2. Since energy plays a vital role in national economic development, the Taiwan government established the Energy Commission under the Ministry of Economic Affairs (MOEA) in November 1979 to formulate and implement the national energy policy. With the rapid industrialization and economic development in the past

decades, the national energy demand and consumption tends to be larger with economic growth, resulting in heavy environmental loadings and high-energy dependence [3]. In 2003, the energy supply, which is divided into indigenous energy and imported energy, totaled 121.2 million kiloliters of oil equivalent (KLOE) [4]. The former includes petroleum 60.2 million KOLE, coal 38.7 million KLOE, nuclear power 9.5 million KOLE, and natural gas (including liquefied natural gas) 8.7 million KLOE. The latter, that mostly comprises hydropower, coal and renewable energy, totaled 4.1 million KLOE in 2003. In contrast to the total energy supply of 31.8 million KLOE in 1982, 64.1 million KLOE in 1992 and 113.2 million KLOE in 2002 [5], the total amount of Taiwan's energy supply obviously increased at an annual average growth rate of 6–7%. It should be noted that the ratio of indigenous energy to imported energy decreased from 13.8% in 1982 to about 3% in 2003.

In recent years, the global environmental issues such as global warming and sustainable development are consecutively raising public concerns. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was declared in Rio De Janeiro (Brazil), followed by the Kyoto Protocol in 1997 [1]. Subsequently, developed and developing countries around the world have prevailingly addressed the mitigation strategies and policies relating to the greenhouse gases (GHGs), especially in carbon dioxide and methane. In response to the Kyoto Protocol adopted in December 1997, the Taiwan government convened the National Energy Conference in May 1998. One of the most important conclusions was to increase the share of renewable energy in Taiwan's total energy supply, up to 3% by the year 2020. In this respect, energy strategies and policies for promoting renewable energy must be active in providing some environmental and financial/economic incentives [6]. With respect to energy policy for economic development and sustainable development, the Executive Yuan has revised and approved "The Energy Policy of the Taiwan Area", implemented by the Energy Commission under the MOEA [5], the primary agency responsible for industrial development and energy policy in the central government level. The relevant points of energy policy include the production of clean energy, mitigation of greenhouse gas emissions and reinforcement of technology research on renewable energy.

In a previous paper, [6], environmental impacts, prospects and policies for renewable energy in Taiwan were reviewed. Thus, the objectives of this paper will further present an overview of government's organizational response to renewable energy development, energy policy and special fund for renewable energy technology development mainly based on the "Renewable Energy Development Plan" approved by the Executive Yuan of Taiwan in January 2002. These approaches and measures have resulted in progress in the renewable energy utilization in recent years. Thus, current status of usage and technology development of renewable energy is thereafter addressed in this paper. Noticeably, current utilization of renewable energy in 2002 is far below the goal of 3% of renewable energy by 2020 in the total energy supply. Due to the highlights in this issue, the National Science Council (NSC), the primary agency responsible for science and technology issues, and the MOEA, have addressed some integrated strategies and R&D programs

to upgrade renewable energy technology. Finally, the paper will focus on the descriptions of R&D projects for biofuel energy in progress, because the renewable energy source will become available and applicable in the near future.

2. Taiwan's organizational response to technology development on renewable energy

According to the Constitution of the Republic of China (Taiwan), the Cabinet (Executive Yuan) is the nation's highest administrative body. As prescribed by the Organic Law of the Executive Yuan, it contains many ministries, departments, administrations, Councils, Commission and central-level organizations. In order to respond to the establishments of the nation on science and technology, the "Science and Technology Advisory Team" was set up under the leadership of the premier. Secondly, relevant ministries and commissions under the Cabinet have taken charge of some aspects of the renewable energy development, as summarized below [7]:

- Ministry of Economic Affairs (MOEA): the Energy Commission under the MOEA is responsible for changing the relative balance of Taiwan's energy sources, enhancing the renewable energy utilization demonstration and public propagation, developing new/clean energy sources and promoting measures on renewable energy usage; the Industrial Development Bureau (IDB), the Small and Mediun Enterprise Administration, and the Department of Industrial Technology under the MOEA are responsible for assisting industrial development on renewable energy, encouraging private enterprises toward renewable energy development on high-efficiency, low-cost, commercialization-scale production technologies and stable electricity-supply technologies; the Bureau of Standards, Metrology and Inspection under the MOEA is responsible for establishing the standards (quality specifications) of photovoltaic system product, refuse-derived fuel, alcoholic gasoline and bio-diesel.
- National Science Council (NSC): responsible for encouraging researches at academic institutions, universities and colleges relating to climate change and development of greenhouse gas reduction and renewable energy technology.
- Environmental Protection Administration (EPA): responsible for greenhouse gas (especially bio-gas from sanitary landfills) reduction, encouraging the public transportation system for adopting alcoholic gasoline and bio-diesel, installing waste-to-energy (including refuse-derived fuel) facilities and promoting existing facilities (incl. cement kiln, fluidized bed, boiler, power plane etc.) for co-combusting general organic wastes.
- Council of Agriculture (COA): responsible for assisting the pig farmers for installing bio-gas combustion or electricity generation from anaerobic wastewater treatment system (both benefits of energy utilization and greenhouse gas reduction).
- Ministry of Interior (MOI): responsible for promoting green labels on buildings and establishing construction standards on solar energy utilization.

- Ministry of Education (MOE): responsible for promoting sustainable development on university's campus, diffusing renewable energy into curricula, and encouraging researchers at universities/colleges to develop renewable energy technology.

3. Government policy and fund for renewable energy technology development

According to the report by the Energy Commission under the MOEA [5], Table 1 shows the development targets at renewable energy, including hydropower, wind energy, solar energy, biomass energy and geothermal energy by 2020. In order to encourage the use of clean energy in Taiwan, the current promotion regulations relating to renewable energy utilization and technology development are mainly based on the Statute for Upgrading Industries (SUI), which was originally promulgated and became effective in December 1990 and was thereafter revised in January 1995, January 2002 and February 2003, respectively. In line with the tasks of promoting the continual use and R&D of renewable energy, the Executive Yuan adopted the "Renewable Energy Development Plan" in January 2002 [6,7]. The Council for Economic Planning and Development (CEPD) will be in charge of coordinating the efforts from central government authorities in promoting renewable energy. In the Plan, important measures and promotions relating to renewable energy technology development (seen in Table 2) are summarized as follows:

- Give the financial incentives, including investment subsides (income tax subsides) and low-interest loans, to enterprises/businesses that utilize renewable energy equipments and technologies. These financial incentives are under consideration to expand into parties, organizations etc. Under the authorization of the SUI, the regulation, known as "*Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy conservation, or emerging/Clean Energy Organizations*", was first promulgated by the Ministry of

Table 1
Development goal of renewable energy in Taiwan[a]

Item	2001		2010		2020	
	Performance	%	Goal	%	Goal	%
Hydro-electric energy	1819 MW	81.7	2050 MW	62.1	2500 MW	38.5
Wind energy	5 MW	0.2	500 MW	15.2	1500 MW	23.1
Geothermal energy	–	0	–	0	150 MW	2.3
Solar photovoltaic	0.3 MW	0	55	1.7	1000 MW	15.3
Solar thermal energy	(103×10^4 m^2)	–	(350×10^4 m^2)	–	(600×10^4 m^2)	–
Biomass energy[b]	403 MW	18.1	695 MW	21.0	1,350 MW	20.7
Sum	2227 MW	100	3300 MW	100	6500 MW	100

[a] *Source*: [5].
[b] Including energy utilization from sugarcane bagasse, rice husk, paper/pulp waste, black liquor, petroleum coke, waste tire, waste plastics, refuse-derived fuel, exclusive of bio-diesel oil.

Table 2
Major measures and approaches for renewable energy development during 2000–2020 in Taiwan

Product/technology	Short term (2000–2004)	Moderate term (2005–2009)	Long term (2011–2020)
Solar water heating	Assistance promotion	Popularization, public awareness	
Photovoltaic	R&D (priority), assistance promotion and related enterprises under supporting	Obligatory ratio by electricity power sectors, assistance demonstration and promotion	Obligatory installation ratio and promotion by electricity power sectors, popularization, public awareness
Wind power	Assistance demonstration	Obligatory installation ratio and promotion by electricity power sectors	
Biomass energy			
Landfill bio-gas for electricity generation	Assistance demonstration	Assistance promotion by electricity rating	Popularization and public awareness
Landfill bio-gas combustion	Assistance demonstration	Assistance promotion	Popularization and public awareness
Waste gasification for electricity generation	R&D and assistance demonstration	Assistance promotion by electricity charge	
Municipal solid waste incineration for electricity generation	Assistance promotion (consecutive)		
Energy utilization from waste	R&D and assistance demonstration	Assistance promotion	
Bio-ethanol/bio-diesel	R&D (priority) and assistance promotion	R&D (priority) and assistance promotion	Assistance promotion
Biomass gasification for electricity generation	R&D		Assistance demonstration and promotion
Bio-hydrogen	R&D		Assistance demonstration and promotion

Source: [7].

Finance (MOF) in July 1997, and thereafter revised in November 1999, July 2000, September 2001 and January 2003, respectively. These specified organizations shall be granted credits on the profit-seeking enterprise income tax for the current year if they themselves use this equipment and/or technology according to the 13% and 10% of total purchase cost (>NT$ 600,000, equivalent to US$ 18,000) for emerging/clean energy utilization equipments and technologies, respectively.

- Establish the databank of renewable energy, and continuously research and develop high-efficiency, low-cost, commercialization-scale production technologies and stable electricity-supply technologies on renewable energy. The Energy Commission under the MOEA has commissioned the Technology and Vocational Center of the National Taiwan Normal University (NTNU) to establish the energy education web (www.energy.tvc.ntnu.edu.tw) for the popularization of energy conservation and renewable energy since 2000. Further, the renewable energy web (www.re.org.tw) has been carried out by the Energy and Resource Lab of the Industrial Technology Research Institute under the finan-

cial support of the Energy Commission. By applying geographic information system (GIS) tool, the databank contains three subsystems, including distribution profile of renewable energy, case study of energy development plan and basic geographic information. The related information on renewable energy technology development is also presented in the Chinese magazines of "Energy Report", "Energy Newsletter" and 'Energy Quarterly" issued by the Energy Commission, and Journal of Solar Energy and New Energy issued by the Chin. Soc. of Solar Energy and New Energy (Taiwan).
- Guide the industrial development on renewable energy sectors, and assist the sectors in promoting the development of low-cost, commercial production technologies and products. Under the authorization of the SUI, the regulation, known as "the Newly Emerging, Important and Strategic Industries" first announced by the MOEA in December 2001, including equipment for new/clean energy, energy saving, greenhouse gas reduction and energy efficiency upgrading. These industries can produce substantial benefits to economic development, an investor (profit-seeking enterprise or individual), who subscribes to the registered stock issued by the company and has held such stock for a period of three years or longer, may deduct the profit-seeking enterprise income tax or the consolidated income tax up to 20% and 10% of the price paid for acquisition of such stock for profit-seeking enterprise and individual, respectively.

Among these promotion measures, the most ambitious is that the procurement charge of electricity from renewable energy will be guaranteed at a fixed rate of NT$ 2.0/kW-h (≒ US$ 0.06/kW-h) by the Statute for Renewable Energy Development (Draft). The law shall aim at the total promotion amount of 3300 MW and 6500 MW in 2010 and 2020, respectively. In order to develop renewable energy, the Statute shall establish a special fund from electricity sector based on its total electricity generation (exclusive of renewable energy source). The fund will be mainly used for the following purposes:

- subsidies of electricity charge for renewable energy.
- subsidies of renewable energy equipments.
- assistances of demonstration and promotion for renewable energy.

It is noted here that the current budgets for energy technology development are mainly from the energy R&D fund and partly from the petroleum fund. Fig. 1 shows the increase trend of input budget for R&D of energy technology by the MOEA [8]. Under the authorization of the Energy Management Law, which was originally promulgated and became effective in August 1980 and was recently revised in January 2002, the energy R&D fund was established to serve the research and development of technology relevant to exploitation of energy sources and alternate energies, and other legal purposes. According to the provision of the fund, incentives or subsidies may be granted to the legal entities or natural persons whose engagement in R&D on energy technology proves to be highly practical. The budget of the special fund is mainly from the contribution of the vertical

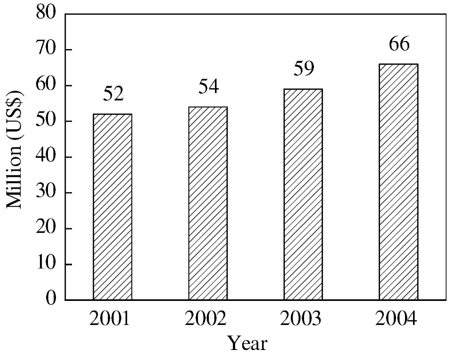


Fig. 1. Input budget of energy technology development by the Energy Commission of the Ministry of Economic Affairs (Taiwan) during 2001–2004.

integrated utilities, oil refinery and oil importer at a percentage of their income generated from the energy supply business. On the other hand, the budget sources of petroleum fund are mainly from oil importers based on the authorization of the Petroleum Administration Law of 2002. One of the legal purposes will be used to implement R&D on energy policy, oil development, and alternative energies. Also, the National Science Council is actively proceeding with R&D for renewable energy at academic institutes, which will be described below.

4. Current status of renewable energy usage and technology development in Taiwan

Due to its geographical features, Taiwan has substantial reserves of renewable energy sources, especially in biomass, solar, wind, and geothermal resources. In 2001, renewable energy production represented about 2200 MW as listed in Table 1 [5]. However, most of this production was highly dependent on hydro-electricity power and biomass sources, including municipal solid waste, animal waste and agricultural by-products. Based on the substantial reduction of GHGs and other air pollutants emissions from the utilization of renewable sources and compared to the use of fossil fuels and biomass wastes, the current government policies described above for the promotion of renewable energy will tend to decrease in the use of biomass wastes and other combustible wastes, and we will expect a progressive increase in the solar energy and wind energy in the near future [6]. According to the "Renewable Energy Development Plan" in Taiwan [7], the government projections during the years from 2002 to 2020 indicate that the cumulative installation capacity is expected to have approximately 6.5×10^6 kW by the end of 2020. The total energy and environmental performances from the Plan were estimated to be about 7.5 million KLOE and approximately 2.2×10^7 metric tons in the equivalent emission reduction of carbon dioxide. The following description is an overview of current status of renewable energy usage and technology development up to 2002 in Taiwan [5,6,8–11]:

- Biomass energy

  - For biogas power generation in the sanitary landfills and anaerobic wastewater treatment plants, the accumulated capacity is now around 20 MW.
  - In order to effectively utilize energy sources from municipal solid waste, the Energy and Resources Lab of the Industrial Technology Research Institute has successfully developed the manufacturing technology of solid refuse-derived (RDF) based on the pilot plant at the design capacity of 200 kg/h, and further begun to build the first RDF demonstration plant with a capacity of processing one metric ton per hour under the supports of Hualien County government and the Energy Commission since 2002.
  - For the technology development on biomass gasification, the Energy and Resources Lab of the Industrial Technology Research Institute has successfully carried out a 90 kW rice hull gasification reactor and a 900 kW circulating fluidization gasification furnace with pilot scale under the support of the Energy Commission.
  - For the technology development on pyrolysis and liquefaction in the manufacturing of bio-oil, one company has commercially operated a pyrolysis system of waste plastics by the technology transfer of the Energy and Resources Lab of the Industrial Technology Research Institute. For the purpose of auxiliary fuel used in boiler or direct use in electricity generator, the resulting bio-oil is further separated and purified into gasoline, Diesel oil and fuel oil in the distillation column.
  - For the technology development on bio-hydrogen: By molecular biotechnology, the researchers at the National Kaohsiung First University of Science and Technology have screened the prevailing microbes for the bio-hydrogen production in the anaerobic fermentation system, set up a hydrogen production measurement system and also carried out the design of the hydrogen production system with the scale of 1000 liter.

- Solar energy

  - For solar water heaters, the installed area of heat collectors has reached 1.14 million m^2. The accumulated area is projected to be 1.3 million m^2 in 2004. For photovoltaic demonstration systems, the total capacity that has been approved for subsidization is 640 kW. The target is to install demonstration systems with a total capacity of 6.7 MW by 2004.
  - For the technology development on solar collector, the Energy and Resources Lab of the Industrial Technology Research Institute has established anti-gravity recycle type heat-pipe collector from solar energy with heat collecting efficiency of over 50%. Also, the vacuum sputtering technology development on selective absorption membrane for solar energy was carried out at the absorbance of 0.93 and reflectance of 0.07.
  - For the technology development on solar energy cooling and air conditioning system, the Energy and Resources Lab of the Industrial Technology Research Institute has also established a solid adsorptive cooling system with refriger-

ation capacity of 1.93 RT and coefficient of performance (COP) of 0.46, and a solid hydrogen storage solar energy with average refrigeration capacity of 1.58 RT and COP of 0.52.
  - For the technology development on photovoltaic system: low-cost, high-efficiency polycrystalline and non-crystalline film cell technology with an efficiency of $\geqq 8\%$ has been successfully developed by the Material Research Lab of the Industrial Technology Research Institute.
  - For the technology upgrading on solar energy applications: including advanced thermal pump heater and heat storage collector from solar energy, the design and manufacturing of solar energy car.

- Wind energy
  - For wind power demonstration systems, the total capacity that has been approved for subsidization is 8.54 MW and the target for 2004 is 18 MW.
  - For the technology development on wind power: on-shore wind power sites with total electricity generation of over 100 MW have been screened according to the potential wind power distribution simulation and evaluation in Taiwan.

5. Current R&D programs in the renewable energy technology

In response to the global change in greenhouse effect and energy supply stability in the future, a "National Energy Convention" thus convened in May 1998 aimed at setting up promotion strategies and action plans on renewable energy in Taiwan. It significantly concluded that the central government shall budget at least NT$ 10 billions (≒US$ 300 millions) for the purposes of new and clean energy (especially renewable energy) promotion assistances and technology development at the first (short-term) stage of 2000-2004 (seen in Table 3). Undoubtedly, the technology development on renewable energy is urgently needed in Taiwan's energy sectors in the near future. Therefore, promoting R&D on the wider use of renewable energy sources have been listed as one of the target goals in the "Challenge 2008—National Development Plan", which was planned and issued by the CEPD of the Executive Yuan in May, 2002.

Under the industrial development and energy policies for promoting productivity and sustainable development in the laws (e.g. SUI), the Department of Industrial Technology and the Energy Commission of the MOEA have commissioned non-profit organizations, such as the Energy and Resources Lab (ERL) and the Material Research Lab (MRL) of the Industrial Technology Research Institute (ITRI), and academic institutes, such as National Taiwan University (NTU), National Kaohsiung First University of Science and Technology (NKFUST), National Cheng Kung University (NCKU), National Chiao Tung University (NCTU), and Yuan Ze University (YZU), and national laboratories, such as Central Geological Survey (CGS), Institute of Nuclear Energy Research (INER) and National Center for Ocean Research (NCOR), to act as technology development and promotion groups or energy technology centers in order to assist industries and organizations

Table 3
Research projects on renewable energy technology development under the supports by the MOEA in Taiwan

Project	Planned institute	Year(s)
Technology development on fuel cell and hydrogen energy utilization	Energy and Resource Lab of ITRI	2001–2004
Study on regulatory system of renewable energy and its establishment of data bank	Energy and Resource Lab of ITRI	2003
Assistance operation for solar heating system promotion and encouragement	National Cheng Kung University	2000–2004
Wind energy demonstration and promotion	Energy and Resource Lab of ITRI	2000–2004
Technology development on renewable energy and mixed/combined electricity generation	Energy and Resource Lab of ITRI	2003–2005
Clean biomass energy research and its application	National Kaohsiung First University of Science and Technology	2000–2004
Bio-energy technology research and its application	Energy and Resource Lab of ITRI	2003–2004
Waste-to-energy utilization technology development and promotion	Energy and Resource Lab of ITRI	2000–2004
Photovoltaic energy demonstration and promotion	Material Research Lab of ITRI	2000–2004
Technology upgrading on solar heating and its application	National Taiwan University	2000–2004
Technology development on solar heating and its application	Energy and Resource Lab of ITRI	2000–2004
Geothermal energy utilization demonstration and promotion	Energy and Resource Lab of ITRI	2000–2001
Feasibility study on electricity generation from ocean energy (heat gradient)	(One engineering consultant co.)	2001

in utilizing renewable energy from various natural sources on the basis of "Industrial Technology Oriented Service Development Program" of the MOEA or "General/Integrated Research Program" of the NSC since the 1990s . It should be noted here that the Energy Commission has also commissioned the Energy Technical Service Center of the China Technical Consultants, Inc. (CTCI) (non-profit organization) to provide professional assistance and counseling in energy conservation as well as its access to advanced energy technologies for domestic industries since the mid-1980s. Table 4 summarizes the major R&D institutes for renewable energy and their roles in the renewable energy technology development in Taiwan. For example, to back up the renewable energy technology, the ERL of the ITRI is developing waste-to-energy (including gasification of biomass wastes, refuse-derived fuel from wastes, and liquefaction of waste plastics) technology and promotion in the 5-year project (2000–2004) under the funds of the Energy Commission [9].

In order to upgrade and prompt the energy technology development by the research institutes, the Energy Commission, in academic cooperation with the NSC, has jointly set up a research project called "Program on Energy Technology

Table 4
The major institutes for renewable energy technology development in Taiwan

Institute	Funding agency	Focus field
Energy and Resource Lab of ITRI[a]	MOEA[b]	Biomass energy from wastes, solar energy (applications in the air-conditioning), fuel cell/hydrogen
Material Research Lab of ITRI	MOEA	Photovoltaic cell
Energy Technical Service Center of the China Technical Consultants, Inc. (CTCI)	MOEA	Energy conservation
New Energy Center in National Taiwan University	MOEA	Solar water heating
Energy Technology and Management Research Center in National Chao Tung University	MOEA	High-efficiency energy technology (applications in the semiconductor industry)
Energy Research Center in National Kaohsiung First University of Science and Technology	MOEA	Bio-hydrogen energy from high-organic wastes
Fuel Cell Center in Yuan Ze University	MOEA/NSC[c]	Fuel cell
Teaching, Research and Application Center for Environmental Resources in Transworld Institute of Technology	MOE[d]	Solar water heating, wind energy
Green Energy Center in Ching Yun University of Technology	MOEA	Photovoltaic system under the technology supports of Material Research Lab of ITRI
Central Geological Survey	MOEA	Geothermal resources
National Center for Ocean Research	NSC	Ocean energy from heat gradient
Taiwan Livestock Research Institute	COA[e]	Bio-methane from animal wastes
Institute of Nuclear Energy Research	AEC[f]	Methanol fuel cell, hydrogen storage by nano-carbon
Taiwan Power Research Institute	TPC[g]	Renewable energy applications
Taiwan Sugar Research Institute	TSC[h]	Bio-ethanol from sugar by-products

[a] Industrial Technology Research Institute.
[b] Ministry of Economic Affairs.
[c] National Science Council.
[d] Ministry of Education.
[e] Council of Agriculture.
[f] Atomic Energy Council.
[g] Taiwan Power Company (government-owned enterprise).
[h] Taiwan Sugar Company (government-owned enterprise).

Development" since 2000. This program was planned to focus on the target topics, including R&D on renewable energy as follows:

- Photovoltaic energy: e.g. photovoltaic cell, photovoltaic cell power system, non-crystalline film cell, single and polycrystalline film cell, new material and design for photovoltaic cell, high-efficiency composite heat/electricity collection system, system modeling and analysis, high-efficiency organic/inorganic hybrid solar cell, non-crystalline silicon and microcrystalline silicon-laminated solar cell components, organic solar cell etc.
- Solar heating energy: e.g. high-efficiency natural circulation water heater design, solar energy power, solar energy air conditioning dehumidification system, non-metal thermal collector, high-efficiency composite heat/electricity collection system, system modeling and analysis etc.
- Bio-energy and waste-to-energy: e.g. bio-diesel, alcoholic gasoline, bio-hydrogen, microbial energy, bio-ethanol, energy crops, waste-to-energy utilization and electricity generation etc.
- Wind energy, geothermal energy and ocean energy: e.g. best site evaluation and analysis of wind energy, offshore wind power generation, high-efficiency wind power generation, geothermal steam utilization, anti-acid and corrosion materials for geothermal utilization, thermal machine for geothermal energy, ocean energy from heat gradient, tidal and wave etc.

On the other hand, the Thermal-Fluid and Energy Division under the Department of Engineering and Applied Science of the NSC began the target-oriented research project called "Special Research Program on Clean Energy" since 2001. In the project of 2003–2004, the research program aims at electricity generation technologies from renewable energy sources, fuel cell and hydrogen energy.

6. Promoting R&D on renewable energy in progress

6.1. Hydrogen from biological conversion of organic wastes/wastewaters

Undoubtedly, hydrogen can be considered as one of the most clean energy sources. Thus, using hydrogen as one of the renewable energy sources has been actively studied in the United States and Japan since the early 1990s [12]. Generally, there are two processes for producing bio-gas containing high content of hydrogen: gasification and anaerobic conversion. In the gasification process, it is the conversion of biomass solid wastes (e.g. agricultural wastes and municipal solid waste) into a medium energy gas mainly made up of carbon monoxide and hydrogen under high temperature ($>1000\ ^{\circ}C$) and medium pressure (up to 20 bar) [13]. In the anaerobic conversion process, it is a biological technology that converts liquid biomass with a high content of carbon into a gas, which mainly contains hydrogen and carbon dioxide, while the production of methane is negligible.

In Taiwan, there are two major bio-hydrogen research projects in progress. One is the "Bio-hydrogen production mechanisms and processes application on multiple substrates" program, which was an integrated project sponsored by the NSC for six years (phase I: 1998–2001; phase II: 2001–2004) [14]. The researchers in the

team from six universities (i.e. National Cheng Kung University, etc.) conducted key elements of six subprojects covering (1) protein and carbohydrate degradation, (2) microbial isolation, (3) use of phototrophs, (4) sludge digestion, (5) system modeling, and (6) microbial identification. The research objectives thus aim at the following factors in bio-hydrogen production: single/multiple carbohydrate substrates (glucose and sucrose) and protein substrate (peptone and glycine); reactor design, including batch tank, complete stirred tank reactor, plug flow reactor, upflow anaerobic sludge blanket bed, and membrane reactor; significant microbial species isolation using 16S rDNA sequencing; identification of by-products (C_1–C_4 acids) resulting from the hydrogen production process; analysis of determining process factors (e.g. pH, temperature, hydraulic retention time, cell growth nutrients); and composition and yield of bio-gas resulting from the biological process. Another project ("R&D on clean biomass energy program") was conducted by the National Kaohsiung First University of Science and Technology (Taiwan) for a five-year project (2000–2004) under the sponsorship of the Energy Commission. The research objectives mainly consist of (1) hydrogen-producing bacteria selection, (2) hydrogen conversion from various organic materials (e.g. food wastes), (3) bioreactor design for anaerobic fermentation, (4) determination of environmental/inhibition factors in bio-hydrogen production, and (5) operation and modeling of pilot-scale fermentation reactor (i.e. 1000 L) for the purposes of scale-up planning and design.

6.2. Bio-crude from fast pyrolysis of agricultural wastes

Fast pyrolysis is a thermochemical process in which the biomass feedstock is rapidly heated and decomposed under the atmospheric pressure in the absence of oxygen or air, vaporizes and condenses to a dark brown tar or liquid (i.e. bio-crude) with a heating value of about half that of conventional fuel oil that can be readily stored or transported. Compared to the traditional pyrolysis processes generally applied for making charcoal, the technology is a more advanced process that can generate high yields (up to 80% wt on dry feed) of liquid under the important operation features [15,16]: (1) very high heating rate (>400 °C/min) and heat transfer rate, (2) finely ground biomass feed (<1 mm), (3) carefully controlled temperature (above 500 °C), and (4) rapid cooling of the pyrolysis vapors to give the bio-crude products.

In Taiwan, rice straw, rice hull, sugarcane bagasse and coconut shell are the most primary agricultural wastes. The total annual generation of these wastes has exceeded 4,000,000 metric tons [11,17]. The current approaches to treatment/disposal of these biomass wastes are mainly dependent on farmland disposal, open burning and arbitrary dumping. However, these methods will create serious environmental problems, such as air pollution and greenhouse gas (e.g. CO_2) emission. Under the funds of the Energy Commission, the research project "Application of Fast Pyrolysis Technology for Manufacturing Biomass Fuel" program has been conducted by the laboratory at the Chia Nan University of Pharmacy and Science (Tainan, Taiwan) since 2003. The objective of the research is to study

the feasibility of using fast pyrolysis technology in inducing heating for manufacturing the bio-fuel from the main agricultural wastes in Taiwan. The important features of the research are to (1) analyze physical and chemical properties of target biomass wastes (i.e. rice husk, rice straw, bagasse and coconut shell), (2) evaluate preliminary operation conditions (e.g. pyrolysis temperature, heating rate) for thermal analysis (i.e. TGA/DTA) of these biomass wastes, (3) design and test performances of fast pyrolysis furnace with domestic vendor, (4) establish preliminary conditions for analysis of biomass fuel, (5) proceed with pyrolysis experiments under different parameters, such as pyrolysis temperature, heating rate and residence time, (6) analyze physical and chemical properties of pyrolysis products (especially bio-crude), (7) establish relationships between characterization of bio-oil thus produced and experimental pyrolysis parameters.

7. Conclusions and recommendations

Although Taiwan is a densely populated nation with only limited natural resources, the renewable energy sources, mainly including solar energy, wind energy and biomass energy, are abundant in this subtropical island country. The key guideline of the nation's energy policy for sustainable development is to ambitiously promote renewable energy. The target share for renewable energy in terms of total energy supply is above 3% by 2020. However, it is obvious from the data presented here that the current status of renewable energy utilization is relatively small compared to total energy and fuel demands, especially when conventional hydroelectric power is excluded. In order to encourage the usage of renewable energy, the Taiwan's Cabinet (Executive Yuan) adopted the "Renewable Energy Development Plan" in January 2002, drew up a plan for the energy technology portion of the "Challenge of Year 2008—National Development Plan" in May 2002, and drafted the Statute for Renewable Energy Development, which was sent from the Cabinet in August 2002 to the Legislative Yuan for its approval. Renewable energy technology development in progress and related law under review in the legislature provide important features, including mission-oriented research and development for renewable energy technology, and regulations on compulsory purchases and guarantees of fixed prices for electricity from renewable energy sources.

It is undoubtedly expected that the Statute for Renewable Energy Development under enacting will greatly drive the energy utilization and technology development from renewable resources in Taiwan. However, there are some recommendations on renewable energy technology development to be addressed as follows:

- Encourage the establishment of large-sized energy enterprises so as to transfer the energy technology to industries.
- Increase and expand the allowance for solar water heater, photovoltaic system, wind power demonstration and bio-gas electricity generation.
- Require high energy-consuming industries (e.g. paper and pulp, petrochemical and food manufacturing) to conduct net energy reduction by utilizing renewable

energy. For example, electricity power is partly generated from the resulting biogas in the anaerobic wastewater treatment and sludge digestion.
- Set up the national laboratory for renewable energy research and development like National Renewable Energy Laboratory (NREL) in the USA.
- Focus on manufacturing technologies of bio-fuel by pyrolysis and gasification, not on biomass combustion from the viewpoint of practical applications.
- Develop pilot-scale bio-technology for hydrogen generation from high-organic content industrial wastewater because hydrogen energy has been recognized as the most clean fuel, with no greenhouse gas emission.
- Demonstrate commercial feasibility of utilizing waste food oils as raw materials of bio-diesel oil, which has been considered as liquid fuel in place of diesel oil.
- Promote the cultivation of energy crops such as sugarcane (for the production of ethanol by alcoholic fermentation) and sunflower (for the production of seed oil by the mechanical extraction).

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References

[1] Bishop PL. Pollution prevention: fundamentals and practice. New York: McGraw-Hill; 2000 (pp. 121–138).
[2] Kemp R. Environmental policy and technical change. Cheltenham, UK: Edward Elgar; 1997 pp. 290–311.
[3] Tsai WT, Chou YH. Government policies for encouraging industrial waste reuse and pollution prevention in Taiwan. Journal of Cleaner Production 2004;12:725–36.
[4] Ministry of Economic Affairs (MOEA), Current status of energy supply and demand of 2003 in Taiwan. Available at http://www.moeaec.gov.tw/10/02/energy%20situation/e5/emain5.html.
[5] Ministry of Economic Affairs (MOEA). The energy situation in Taiwan (ROC). MOEA, Taipei, Taiwan, 2003.
[6] Tsai WT, Chou YH. Overview of environmental impacts, prospects and policies for renewable energy in Taiwan. Renewable and Sustainable Energy Reviews (in press, 2004).
[7] Council for Economic Planning and Development (CEPD). Renewable energy development plan. Taipei, Taiwan: CEPD, 2002.
[8] National Science Council (NSC). The Yearbook of science and technology in Taiwan (ROC). Taipei, Taiwan: NSC, 2003.
[9] Chen JH. Gasification of Agricultural wastes at ERL: achievements and applications. In: Conference on Waste-to-Energy and High Temperature Gas Cleanup Technologies, Oct. 29–30, Taipei, Taiwan, 2003.
[10] Wu KT, Lu WC, Lee HT. Current status and development of biomass energy and its application. J. Solar Energy New Energy Soc. R.O.C. 2003;8(2):27–30.
[11] Tsai WT, Chou YH. Progress in energy utilization from agrowastes in Taiwan. Renewable and Sustainable Energy Reviews 2004;8:461–81.
[12] Lay JJ. Current status of biohydrogen-producing technology development by anaerobic process (in Chinese). The Institute of Environmental Engineering 2003;13(2):24–9.

[13] Klass DL. Biomass for renewable energy, fuels,and chemicals. San Diego, USA: Academic Press; 1998 (pp. 463–469).
[14] Cheng SS. The research status of biohydrogen production in Taiwan. In: 2003 International Bioenergy Symposium, November 11–12, Taipei, Taiwan, 2003.
[15] Bridgwater AV, Meier D, Radlein D. An overview of fast pyrolysis of biomass. Organic Geochemistry 1999;30:1479–93.
[16] Bridgwater AV, Peacocke GVC. Fast pyrolysis process for biomass. Renewable and Sustainable Energy Reviews 2000;4:1–73.
[17] Council of Agriculture (COA). Yearbook of Agricultural Statistics. COA, Taipei, Taiwan, 2002.